

**AN INVESTIGATION INTO THE EFFECTIVENESS OF VIRTUAL
REALITY-BASED LEARNING**

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DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Elinda Ai Lim Lee

*To my husband Boon Leng and sons Timothy and Aaron for their continuing love
and support*

ABSTRACT

This study focused on the effectiveness of using desktop virtual reality (VR) for learning. It addressed the question: Does, and how does, desktop VR influence the cognitive and affective learning outcomes? Cognitive outcome was measured through academic performance whereas affective learning outcomes were measured through perceived learning effectiveness and satisfaction.

The main aims of this study were thus two-fold. First, it investigated “Does desktop VR influence the learning outcomes?” by comparing a desktop VR-based learning environment and a conventional classroom learning practice, and it further conducted the aptitude-by-treatment interaction research to determine if individual differences interact with different learning environments. Two learners’ aptitudes were studied: spatial ability and learning style. In addition, individual differences were further analyzed for the VR-based learning environment because their influence in desktop VR-based learning has been rarely studied. An evaluation that employed a quasi-experimental design was conducted to investigate the learning effectiveness of desktop VR-based learning, and to investigate the effect of learners’ aptitudes on learning. A total of 370 students, aged between 15 to 17 years old from four randomly selected co-education Malaysian secondary schools participated in this study. The findings of this study have supported the general hypothesis that the VR-based learning environment positively affects the cognitive and affective domains of learners. This study has provided empirical evidence on the merit of using desktop VR for learning. Furthermore, it was found that desktop VR could accommodate learners’ individual differences in terms of learning styles.

Next, the research focused on the development of a theoretical model of determinants for effective desktop VR-based learning to understand how a desktop VR system is capable of enhancing and improving the quality of student learning, and the types of students that would benefit from this technology. Various relevant constructs and measurement factors were identified to examine how desktop VR enhances the learning outcomes and the hypothesized model was analyzed using structural equation modeling (SEM). By tradition, the practice of applying correlation analysis to data and hypotheses does not reflect the causal relationships between constructs, but SEM produces a highly viable alternative in determining the causal relationships among constructs. This type of analysis is lacking in desktop VR-based learning.

In the hypothesized model of this study, VR features indirectly influenced the learning outcomes through the mediation of usability (interaction experience) and learning experience. Learning experience which was individually measured by the psychological factors—that is, presence, motivation, cognitive benefits, control and active learning, and reflective thinking—took central stage in affecting the learning outcomes. The moderating effects of student characteristics such as spatial ability and learning style were also examined. Moreover, latent mean difference testing in SEM was conducted to determine the influence of student characteristics on the perception of VR features in the desktop VR-based learning environment. The findings have supported the indirect effect of VR features on the learning outcomes, which was mediated by the usability and learning experience. The results show instructional designers and VR developers how to improve the learning effectiveness

and further strengthens their desktop VR-based learning implementation. Furthermore, academia can use the findings of this study as a basis to initiate other related studies in the desktop VR-based learning area.

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TABLE OF CONTENTS

Abstract	iii
Acknowledgement	vi
List of Figures	xii
List of Tables.....	xv
List of Definitions	xix
List of Abbreviations.....	xxv
List of Publications and Contributions of the Thesis.....	xxvii

CHAPTER 1 INTRODUCTION

1.0 Background	1
1.1 Problem Statement	4
1.2 Purpose of the Study	8
1.3 Research Objectives	10
1.4 Research Approaches	11
1.5 Significance of Research.....	13
1.6 Outline of the Thesis	17

CHAPTER 2 LITERATURE REVIEW

2.0 Overview	20
2.1 What is VR?	20
2.2 Types of VR	22
2.3 Virtual Reality Applications in Instructional Settings	24
2.4 VR and the Constructivist Learning Model	30
2.5 Aptitude-by-Treatment Interactions (ATI).....	34
2.5.1 Spatial Ability and VR.....	36
2.5.2 Learning Style and VR.....	38
2.6 Theoretical Foundation for a Desktop VR-based Learning Environment	42
2.7 Summary	56

CHAPTER 3 RESEARCH FRAMEWORK AND HYPOTHESES DEVELOPMENT

3.0 Overview	58
3.1 Framework for Determining the Effects of a Desktop VR-based Learning Environment and ATI Research	58
3.2 Hypotheses for Determining the Effects of a Desktop VR-based Learning Environment and ATI Research.....	59
3.3 Framework and Model for Evaluating How Desktop VR Enhances Learning Outcomes	61
3.3.1 VR Features.....	64
3.3.2 Usability	66
3.3.3 Presence.....	68
3.3.4 Motivation.....	69

3.3.5	Cognitive Benefits.....	72
3.3.6	Control and Active Learning.....	73
3.3.7	Reflective Thinking.....	75
3.3.8	Learning Outcomes	77
3.3.9	Student Characteristics.....	78
3.4	Hypotheses for Evaluating How Desktop VR Enhances Learning Outcomes.....	79
3.5	Summary	82

CHAPTER 4 METHODOLOGY

4.0	Overview	83
4.1	Research Design	83
4.2	Population and Sample.....	85
4.3	Development of the Measurement Instruments	86
4.3.1	Pretest and Posttest.....	88
4.3.1.1	Scoring	89
4.3.1.2	Test Validity.....	89
4.3.1.3	Test Reliability.....	89
4.3.2	Kolb Learning Style Inventory.....	90
4.3.3	Spatial Ability Test	92
4.3.4	Perceived Learning Effectiveness	93
4.3.5	Satisfaction.....	93
4.3.6	Representational Fidelity	94
4.3.7	Immediacy of Control	94
4.3.8	Perceived Usefulness	94
4.3.9	Perceived Ease of Use.....	94
4.3.10	Presence.....	95
4.3.11	Motivation.....	95
4.3.12	Cognitive Benefits.....	95
4.3.13	Control and Active Learning.....	96
4.3.14	Reflective Thinking.....	96
4.4	Software	96
4.5	Data Collection Procedures	101
4.5.1	Actual Study.....	101
4.5.2	Pilot Study.....	102
4.6	Data Analysis Technique	103
4.6.1	Actual Study.....	103
4.6.1.1	Statistical Analysis for Determining the Learning Effectiveness of a Desktop VR-based Learning Environment.....	104
4.6.1.2	Statistical Analysis for Evaluating How VR Enhances Learning Outcomes.....	105
4.6.1.2.1	Measurement Model Development	107
4.6.1.2.2	Structural Model Evaluation	110
4.6.1.2.3	Moderating Effects Analysis	113
4.6.2	Pilot Study	114
4.7	Results of Pilot Study.....	115

4.7.1	Number of Samples.....	115
4.7.2	Evaluation of Posttest.....	115
4.7.3	Reliability Test of Measurement Instruments.....	117
4.8	Summary	119

CHAPTER 5 RESULTS: LEARNING EFFECTIVENESS OF A DESKTOP VR-BASED LEARNING ENVIRONMENT AND ATI RESEARCH

5.0	Overview	121
5.1	Characteristics of Sample.....	122
5.2	Distribution of Learners	122
5.3	Homogeneity of Pretest.....	123
5.4	Testing Assumption for T-test and Two-way ANOVA.....	124
5.5	Testing of Hypotheses	131
5.5.1	Testing of H ₀₁	132
5.5.2	Testing of H ₀₂	133
5.5.3	Testing of H ₀₃	133
5.5.4	Testing of H ₀₄	136
5.5.5	Testing of H ₀₅	140
5.5.6	Testing of H ₀₆	142
5.5.7	Testing of H ₀₇	145
5.5.8	Testing of H ₀₈	148
5.5.9	Testing of H ₀₉	150
5.5.10	Testing of H ₁₀	153
5.5.11	Testing of H ₁₁	156
5.5.12	Testing of H ₁₂	156
5.5.13	Testing of H ₁₃	157
5.5.14	Testing of H ₁₄	157
5.5.15	Testing of H ₁₅	158
5.5.16	Testing of H ₁₆	160
5.5.17	Testing of H ₁₇	160
5.6	Summary of Hypotheses Testing	161
5.7	Summary	163

CHAPTER 6 RESULTS: HOW DOES DESKTOP VR ENHANCE LEARNING OUTCOMES?

6.0	Overview	166
6.1	Characteristics of Sample.....	167
6.2	Evaluation of Assumptions for Confirmatory Factor Analysis.....	167
6.2.1	Normality	167
6.2.2	Sample Size.....	168
6.3	Measurement Models	169
6.3.1	VR Features.....	171
6.3.2	Presence.....	172
6.3.3	Motivation.....	173
6.3.4	Cognitive Benefits.....	173
6.3.5	Control and Active Learning.....	174

6.3.6	Reflective Thinking.....	174
6.3.7	Usability	174
6.3.8	Learning Outcomes	176
6.4	Discriminant Validity	178
6.5	Analysis of the Structural Model	180
6.5.1	Total Effects Analysis	185
6.5.2	Individual Effect of Mediating Variables	187
6.6	Moderating Effects of Student Characteristics.....	188
6.7	Latent Mean Testing.....	190
6.8	Summary	192

CHAPTER 7 DISCUSSION

7.0	Overview	196
7.1	Effects of the Learning Modes on Learning.....	197
7.1.1	Cognitive Learning Outcome.....	197
7.1.2	Affective Learning Outcome.....	202
7.2	Interaction Effects	203
7.2.1	Interaction Effect of Spatial Ability and Learning Mode on Cognitive Learning Outcome.....	203
7.2.2	Interaction Effect of Spatial Ability and Learning Mode on Affective Learning Outcome.....	209
7.2.3	Interaction Effect of Learning Style and Learning Mode on Cognitive Learning Outcome.....	210
7.2.4	Interaction Effect of Learning Style and Learning Mode on Affective Learning Outcome.....	210
7.3	VR and Individual Differences	211
7.3.1	Effects of VR-based Learning on Cognitive Learning Outcome for Learners with Different Spatial Abilities	211
7.3.2	Effects of VR-based Learning on Affective Learning Outcome for Learners with Different Spatial Abilities	212
7.3.3	Effects of VR-based Learning on Cognitive Learning Outcome for Learners with Different Learning Styles	213
7.3.4	Effects of VR-based Learning on Affective Learning Outcome for Learners with Different Learning Styles	214
7.4	Theoretical Model for Evaluating How Desktop VR Enhances Learning Outcomes.....	215
7.4.1	Causal Path.....	217
7.4.1.1	Presence	217
7.4.1.2	Motivation.....	218
7.4.1.3	Cognitive Benefits	219
7.4.1.4	Control and Active Learning	220
7.4.1.5	Reflective Thinking	222
7.4.1.6	Usability	223
7.4.1.7	VR Features	225
7.4.2	Moderating Effects of Learner Characteristics	227
7.4.3	Latent Mean Testing	229
7.5	Summary	229

CHAPTER 8 CONCLUSIONS

8.0	Summary of the Research and Its Contributions.....	233
8.1	Limitations of the Study	234
8.2	Recommendations for Future Investigations.....	236
8.3	Implications of the Study	237
8.3.1	Conceptual Framework and Theoretical Model of How Desktop VR Enhances Learning Outcomes.....	237
8.3.2	A VR-based Learning Environment—An Effective Alternative ...	238
8.3.3	Aptitude-by-Treatment Interaction Study	239

APPENDICES

Appendix A	Data Collection Procedures for VR Mode (Actual Study).....	241
Appendix B	Data Collection Procedures for Non-VR Mode (Actual Study).....	245
Appendix C	Pretest/Posttest (Actual Study).....	248
Appendix D	Initial Questionnaire (Actual Study)	255
Appendix E	Final Questionnaire for VR Mode (Actual Study)	258
Appendix F	Final Questionnaire for Non-VR Mode (Actual Study).....	268
Appendix G	Posttest Item Analyses (Pilot Test)	273
Appendix H	Latent Mean Testing.....	276

REFERENCES	279
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LIST OF FIGURES

Figure 1.1:	Research framework for determining the effects of a desktop VR-based learning environment and aptitude-by-treatment interaction research.....	12
Figure 1.2:	Conceptual framework for outcomes and their causal relationships in a desktop VR-based learning environment.....	12
Figure 1.3:	Overview of thesis.....	18
Figure 2.1:	Disordinal interaction.....	35
Figure 2.2:	Ordinal interaction.....	35
Figure 2.3:	Kolb’s learning styles and learning modes (Adapted from Kolb, 1984).....	40
Figure 2.4:	Theoretical model describing how VR features, concept to be learned, learner characteristics, and the interaction and learning experiences work together to influence the learning outcomes in immersive VR learning environments (Salzman et al., 1999).....	43
Figure 2.5:	A framework for technology-mediated learning research (Alavi & Leidner, 2001).....	47
Figure 2.6:	Dimensions and antecedents of virtual learning environment effectiveness (Piccoli et al., 2001).....	48
Figure 2.7:	Research framework of Benbunan-Fich and Hiltz (Benbunan-Fich & Hiltz, 2003).....	49
Figure 2.8:	Framework of outcomes and their causal relationships in CSCLIP (Sharda et al., 2004).....	51
Figure 2.9:	Theoretical framework for technology-mediated learning (Wan et al., 2007).....	52
Figure 3.1:	Model for evaluating how desktop VR enhances learning outcomes.....	64
Figure 3.2:	Hypothesized relationships among constructs.....	80
Figure 4.1:	Two-group pretest-posttest quasi-experimental design.....	84

Figure 4.2:	The factorial design to study the effects of learning mode and spatial ability on posttest score, perceived learning effectiveness and satisfaction	85
Figure 4.3:	The factorial design to study the effects of learning mode and learning style on posttest score, perceived learning effectiveness and satisfaction	85
Figure 4.4:	Kolb’s learning styles (Adapted from Kolb, 1984)	91
Figure 4.5:	Screenshot of the desktop VR-based learning environment, the V-Frog™ (Courtesy of Tactus Technologies)	98
Figure 4.6:	The virtual scalpel cuts the frog, just like in a real dissection (Courtesy of Tactus Technologies)	98
Figure 4.7:	The skin is being pulled back with the tweezers (Courtesy of Tactus Technologies)	99
Figure 4.8:	The internal organs are exposed after the membrane is removed (Courtesy of Tactus Technologies)	99
Figure 4.9:	Query tool is used to identify the organ (Courtesy of Tactus Technologies)	100
Figure 4.10:	The comparison of human and frog’s heart. Magic wand can be used to animate the heartbeats (Courtesy of Tactus Technologies).....	100
Figure 5.1:	Histogram of satisfaction for the VR mode.....	130
Figure 5.2:	Normality probability plot of satisfaction for the VR mode	131
Figure 5.3:	Plot of interaction between learning mode and spatial ability, related to performance achievement.....	138
Figure 5.4:	Plot of interaction between learning mode and spatial ability, related to perceived learning effectiveness	142
Figure 5.5:	Plot of interaction between learning mode and spatial ability, related to satisfaction.....	144
Figure 5.6:	Plot of interaction between learning mode and learning style, related to performance achievement.....	147
Figure 5.7:	Plot of interaction between learning mode and learning style, related to perceived learning effectiveness	150

Figure 5.8:	Plot of interaction between learning mode and learning style, related to satisfaction.....	152
Figure 6.1:	Structural equation model showing the standardized loading for each path, and the R^2 for each dependent variable in the model	183
Figure 7.1:	Total cognitive load (Adapted from Cooper, 1998)	200
Figure 7.2:	An illustration of total cognitive load exceeding mental resources (Adapted from Cooper, 1998)	200
Figure 7.3:	The organ is highlighted in red and the labeling is provided when it is activated with the query tool	207

LIST OF TABLES

Table 2.1:	Constructivist versus traditional learning methods (Adapted from Jonassen et al., 1999).....	31
Table 2.2:	The technical capabilities of VR in supporting the constructivist learning principles (Chen & Teh, 2000).....	33
Table 2.3:	Comparison between the immersive VR theoretical model by Salzman et al. (1999) and technology mediated models.....	54
Table 2.4:	Related references about the factors relevant to desktop VR-based learning.....	54
Table 4.1:	Measurement instruments for various stages of treatment.....	87
Table 4.2:	Internal consistency alphas for the scale scores of the KLSI 3.1 (Kolb & Kolb, 2005).....	92
Table 4.3:	Summary of the guidelines for model fit.....	113
Table 4.4:	Guidelines for interpreting item discrimination index (Hopkins, 1998).....	115
Table 4.5:	Test of normality for posttest.....	116
Table 4.6:	Cronbach's alpha for posttest with 32 items.....	117
Table 4.7:	Reliability test of instruments.....	118
Table 5.1:	Cross tabulation of learning mode and gender.....	122
Table 5.2:	Virtual reality knowledge of students in the VR mode.....	123
Table 5.3:	Levene's test of equality of variance of pretest across VR mode and Non-VR mode.....	124
Table 5.4:	Pretest mean score, standard deviation and t-test of pretest of VR mode ($N = 210$) and Non-VR mode ($N = 160$).....	124
Table 5.5:	Test of normality for posttest, perceived learning effectiveness, satisfaction and gain score for the VR mode.....	128
Table 5.6:	Test of normality for posttest, perceived learning effectiveness and satisfaction for the Non-VR mode.....	129

Table 5.7:	Test of normality for posttest, perceived learning effectiveness and satisfaction for the whole sample	129
Table 5.8:	Assessment of normality with skewness and kurtosis for perceived learning effectiveness and satisfaction	130
Table 5.9:	Means, standard deviations, and standard errors of posttest, perceived learning effectiveness and satisfaction by learning mode	134
Table 5.10:	T-test of posttest, perceived learning effectiveness and satisfaction by learning mode	135
Table 5.11:	Two-way ANOVA of posttest by learning mode and spatial ability	137
Table 5.12:	Means, standard deviations of posttest by learning mode and spatial ability	137
Table 5.13:	T-test of posttest by learning mode for high spatial ability learners	139
Table 5.14:	T-test of posttest by learning mode for low spatial ability learners .	139
Table 5.15:	Two-way ANOVA of perceived learning effectiveness by learning mode and spatial ability.....	141
Table 5.16:	Means, standard deviations of perceived learning effectiveness by learning mode and spatial ability.....	141
Table 5.17:	Two-way ANOVA of satisfaction by learning mode and spatial ability	143
Table 5.18:	Means, standard deviations of satisfaction by learning mode and spatial ability	144
Table 5.19:	Two-way ANOVA of posttest by learning mode and learning style.....	146
Table 5.20:	Means, standard deviations of posttest by learning mode and learning style	147
Table 5.21:	Two-way ANOVA of perceived learning effectiveness by learning mode and learning style	149
Table 5.22:	Means, standard deviations of perceived learning effectiveness by learning mode and learning style.....	149

Table 5.23:	Two-way ANOVA of satisfaction by learning mode and learning style.....	151
Table 5.24:	Means, standard deviations of satisfaction by learning mode and learning style	152
Table 5.25:	Means, standard deviations of posttest, perceived learning effectiveness, satisfaction and gain score for high and low spatial ability learners in the VR mode.....	154
Table 5.26:	T-test of posttest, perceived learning effectiveness, satisfaction and gain score for high and low spatial ability learners in the VR mode	155
Table 5.27:	Means, standard deviations of posttest, perceived learning effectiveness, satisfaction and gain score for accommodator learners and assimilator learners in the VR mode	158
Table 5.28:	T-test of posttest, perceived learning effectiveness, satisfaction and gain score for accommodator learners and assimilator learners in the VR mode	159
Table 5.29:	Summary of the findings to research questions 1–6 and hypotheses testing	165
Table 6.1:	Assessment of normality	168
Table 6.2:	Exploratory principal component and internal consistency analysis with actual data	170
Table 6.3:	Unstandardized parameter estimates (standardized parameter estimates), correlation matrix and validity measures for VR features	172
Table 6.4:	Unstandardized parameter estimates (standardized parameter estimates), correlation matrix and validity measures for usability ..	176
Table 6.5:	Unstandardized parameter estimates (standardized parameter estimates), correlation matrix and validity measures for learning outcomes.....	178
Table 6.6:	Implied correlation between the variables in the model	179
Table 6.7:	Standardized loading, C.R. and goodness-of-fit measure for the hypothesized model	182
Table 6.8:	Standardized total effects on dependent variables	186

Table 6.9:	Individual effect of mediators	187
Table 6.10:	Spatial ability moderating effects	188
Table 6.11:	Learning style moderating effects	188
Table 6.12:	Latent mean difference across groups (for examining the main effects of spatial ability and learning style)	191
Table 7.1:	Summary of the hypotheses investigated in the hypothesized model	216

LIST OF DEFINITIONS

To ensure that the terminology used in this thesis is clear, this section includes the definition of the key terms used throughout the thesis.

An accommodator learner: A learner who fulfills Kolb's definition of accommodator, a diverger learner with stronger Kolb's characteristics of concrete experience than reflective observation, and a converger learner with stronger Kolb's characteristics of active experimentation than abstract conceptualization.

An assimilator learner: A learner who fulfills Kolb's definition of assimilator, a diverger learner with stronger Kolb's characteristics of reflective observation than concrete experience, and a converger learner with stronger Kolb's characteristics of abstract conceptualization than active experimentation.

A high spatial ability learner: A learner who scores above the median in the spatial ability test.

A low spatial ability learner: A learner who scores below the median in the spatial ability test.

Cognitive benefits: It refers to better memorization, understanding, application and overall view of the lesson learned.

Construct: See *latent variable*.

Control and active learning: It refers to learner control and active participation while interacting with the virtual reality system. Learners can make their own decision on their learning pace, sequencing, content of instruction, and amount of practice in a learning environment (Kinzie, Sullivan, & Berdel, 1988; Milheim & Martin, 1991).

Conventional classroom learning method: A learning environment with PowerPoint slides based on the lecture method. Information and knowledge were transmitted by teachers to students.

Desktop VR: An interactive three-dimensional computer generated image that can be manipulated. It is implemented on a conventional personal computer without introducing any additional peripheral (Chen, Toh, & Wan, 2004, Neale & Nichols, 2001; Strangman & Hall 2003; Inoue 2007), and is also referred to as a non-immersive VR (Aoki, Oman, Buckland, & Natapoff, 2008; Ausburn & Ausburn, 2004; Chen et al., 2004; Inoue, 2007; Youngblut, 1998).

Desktop VR-based learning environment: A self-directed learning environment with desktop virtual reality.

Immediacy of control: The ability to change the view position or direction, giving the impression of smooth movement through the environment, and the ability to pick up, examine and manipulate objects within the virtual environment (Dalgarno, Hedberg, & Harper, 2002).

Indicator: Observed value used as measure of a latent variable. It is also known as observed or measured or manifest variable (Hair, Black, Babin, Anderson, & Tatham, 2006).

Latent variable: Operationalization of a construct in structural equation modeling. It is also known as a construct, which cannot be measured directly but can be represented or measured by one or more indicators (Hair, et al., 2006).

Learning experience: A psychological state or subjective phenomenon that resulted from the learner's observation and interaction with objects, entities and/or events in the VR-based learning environment (Schuemie, Van Der Straaten, Krijin, & Van Der Mast, 2001).

Learning outcomes: The learning effectiveness of the virtual reality-based learning environment which is measured by performance achievement, perceived learning effectiveness and satisfaction.

Learning style: One's preferred method of perceiving and processing information (Kolb, 1984).

Measured variable: See *indicator*.

Measurement model: A SEM model that specifies the relationships between the observed variables and each latent variable (Byrne 2001; Hair et al., 2006).

Motivation: It refers to the magnitude and direction of behavior. It is the choices people make as to what experiences or goals they will approach or avoid, and the degree of effort they will exert in that respect (Keller, 1983, p. 389).

Non-VR mode: A conventional learning mode that relies on the lecture method. PowerPoint slides were used to deliver the lecture.

Observed variable: See *indicator*.

Perceived ease of use: It is the degree to which a person believes that using a particular system would be free of effort (Davis, 1989).

Perceived learning effectiveness: It is the user's perception of the learning quality in the VR-based learning environment.

Perceived usefulness: It is defined as the extent to which individuals believe a system will help them perform (Davis, 1989).

Performance achievement: The academic achievement of a learner after interacting with the VR system, which is measured by the posttest scores.

Reflective thinking: It is defined as active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the conclusion to which it tends (Dewey, 1933, p. 9).

Representational fidelity: The scene realism provided by the rendered 3-D images, and the scene realism provided by temporal changes to these images (Dalgarno, et al., 2002).

Presence: The user's subjective psychological response to a system. It is a human reaction to a given level of immersion (Slater, 2003).

Satisfaction: The affective attitude or response of a user towards the VR-based learning environment.

Spatial ability: It refers to a group of cognitive functions and aptitudes that is crucial in solving problems that involve manipulating and processing visuo-spatial information (Bodner & Guay, 1997; Hannafin, Truxaw, Vermillion, & Liu, 2008; Lajoie, 2008; Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005), because it is the mental process used to perceive, store, recall, create, edit and communicate a spatial image (Linn & Petersen, 1985).

Structural equation modeling (SEM): A multivariate data analysis technique used to estimate a series of interrelated dependence relationships simultaneously.

Structural model: A model that defines the interrelationship among the latent variables in SEM (Byrne 2001, Hair et al., 2006).

Usability: The quality and accessibility of the virtual reality software used in this study which is measured by perceived usefulness and perceived ease of use.

Virtual reality (VR): A 3-D synthetic environment that allows users to interact intuitively in real time with the virtual world and provides a feeling of immersion to the users (Allen et al., 2002; Auld, 1995; Ausburn & Ausburn, 2004; Ausburn & Ausburn, 2008; Ausburn, Martens, Washington, Steele, & Washburn, 2009; Beier, 2004; Burdea & Coiffet, 2003; Inoue, 2007; Pan, Cheok, Yang, Zhu, & Shi, 2006; Roussou, 2004; Strangman & Hall, 2003). It refers to both non-immersive and immersive VR (Ausburn & Ausburn, 2004; Beier, 2004; Inoue, 2007; Strangman & Hall, 2003).

VR affordances: The qualities of the VR learning environment which include scene realism and immediacy of control that allow an individual to perform an action in the learning environment.

VR features: The attributes of the desktop virtual reality.

VR mode: A learning mode that employs the desktop VR-based learning environment. The virtual reality software, V-FrogTM is used for learning.

LIST OF ABBREVIATIONS

AC	:	Abstract conceptualization
AE	:	Active experimentation
AGFI	:	Adjusted goodness-of-fit index
AMOS	:	Analysis of Moment Structures
ANCOVA	:	Analysis of covariance
ANOVA	:	Analysis of variance
ATI	:	Aptitude-by-treatment Interaction
CAL	:	Computer-assisted learning
CAVE	:	Cave Automatic Virtual Environment
CE	:	Concrete experience
CFI	:	Comparative fit index
CSCLIP	:	Computer-supported collaborative learning requiring immersive presence
C-Vision	:	Collaborative Virtual Interactive Simulations
EVL	:	Electronic Visualization Laboratory
GFI	:	Goodness-of-fit index
HMDs	:	Head-mounted devices
IMI	:	Intrinsic Motivation Inventory
KLSI	:	Kolb Learning Style Inventory
KMO	:	Kaiser-Meyer-Olkin
M	:	Mean
MARVEL	:	Virtual Laboratory in Mechatronics
NICE	:	Narrative-based, Immersive, Constructionist/Collaborative Environments

PIP	:	Personal Interaction Panel
P _U	:	Upper Group
P _L	:	Lower Group
RMSEA	:	Root mean square error of approximation
R ²	:	Squared multiple correlations
RO	:	Reflective observation
SD	:	Standard deviation
SEM	:	Structural Equation Modeling
SPSS	:	Statistical Package for Social Sciences
TAM	:	Technology acceptance model
TLI	:	Tucker Lewis Index
TRA	:	Theory of Reasoned Action
VR	:	Virtual reality
VRML	:	Virtual Reality Modeling Language
VRPS	:	Virtual Reality Physics Simulation
X3D	:	eXtensible 3D Graphics
2-D	:	Two-dimensional
3-D	:	Three-dimensional

LIST OF PUBLICATIONS AND CONTRIBUTIONS OF THE THESIS

Journal Paper

- J1. Lee, E. A.-L., Wong, K. W. (2008). A Review of Using Virtual Reality for Learning, *Transactions on Edutainment I*, LNCS 5080, 231-241.
- J2. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). How Does Desktop Virtual Reality Enhance Learning Outcomes? A Structural Equation Modeling Approach, *Computers and Education*, 55(4), 1424 – 1442
- J3. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). Learning with Virtual Reality: Its Effects on Students with Different Learning Styles. *Transactions of Edutainment IV*, LNCS 6250, 79 – 90.
- J4. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2010). Learning with Non-immersive Virtual Reality: The Role of Learners' Spatial Ability, Paper submitted to *Virtual Reality* (Under review).

Conference Paper

- C1. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2008). Virtual Reality: An Emerging Technology for Learning. *Proceedings of the Ninth Postgraduate Electrical Engineering & Computing Symposium*, Perth, Australia.
- C2. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Educational Values of Virtual Reality: The Case of Spatial Ability. In C. Ardil (Ed.) *Proceedings of the World Academy of Science, Engineering and Technology*, Paris, France.
- C3. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Learning Effectiveness in a Desktop Virtual Reality-Based Learning Environment. In S. C. Kong, H. Ogata, H. C. Arnseth, C. K. K. Chan, T. Hiroshima, F. Klett, J. H. M. Lee, C. C. Liu, C. K. Looi, M. Milrad, A. Mitrovic, K. Nakabayashi, S. L. Wong & S. J. H. Yang (Eds.), *Proceedings of the 17th International Conference on Computers in Education [CDROM]*. Hong Kong: Asia-Pacific Society for Computers in Education.
- C4. Lee, E. A.-L., Wong, K. W., & Fung, C. C. (2009). Virtual Reality and Performance: An Approach in the Light of Spatial Ability. *Proceedings of the Tenth Postgraduate Electrical Engineering & Computing Symposium*, Perth, Australia.

Summary of the Contributions of the Thesis

Chapter	Contributions	Paper No.
Chapter 1— Introduction Chapter 2— Literature Review	Literature survey on previous work to apply virtual reality (VR) technologies for learning. Literature search on frameworks that could guide desktop VR-based learning development efforts. The technical capability of VR to support constructivist learning principles was presented.	J1, C1
Chapter 2— Literature Review Chapter 3— Research Framework & Hypotheses Development	The articulation of the impact of virtual reality in helping learners with different spatial abilities to create internal representations of complex three-dimensional structures, such competence being of paramount importance in the field of science and mathematics. The proposal of aptitude-by-treatment interaction research to study the effect of individual differences on different instructional treatments.	C2
Chapter 5— Results : Learning Effectiveness of a Desktop VR-based Learning Environment and ATI Research Chapter 7— Discussion Chapter 8— Conclusions	The findings of this study contribute to our understanding of the learning outcomes of a desktop VR-based learning environment and provide empirical evidence of the merit of desktop VR-based learning to educators.	C3
	The learning effectiveness in desktop VR-based learning could be justified and thus used to encourage the application of VR in educational settings to improve students' performance. Furthermore, to provide the students a positive, fun and valuable learning experience.	
	The findings enlighten educators on the influence of a desktop VR-based learning environment on learners with different spatial abilities.	C4
	This study also investigated the effects of VR on learners with different learning styles. The findings imply that VR provides equivalent cognitive and affective benefits to learners with different learning styles, and it could accommodate individual differences with regards to students' learning styles.	J3

Chapter	Contributions	Paper No.
	<p>Aptitude-by-treatment interaction (ATI) research was conducted to investigate the interaction effect between the learning modes (VR and Non-VR mode) and the learners' spatial abilities, with regard to students' performance achievement. The finding is in agreement with the ability-as-compensator hypothesis where the VR mode benefits more to the low spatial ability learners.</p>	J4
<p>Chapter 2— Literature Review Chapter 3— Research Framework & Hypotheses Development Chapter 4— Methodology Chapter 6— Results : 'How Does Desktop VR Enhance Learning Outcomes?' Chapter 7— Discussion Chapter 8— Conclusions</p>	<p>A broad framework that identifies the theoretical constructs and their relationships in a desktop VR-based learning environment has been developed and the fit of the theoretical model has been systematically and empirically tested with structural equation modeling. The results supported the indirect effect of VR features on the learning outcomes, which was mediated by the interaction experience (i.e. usability) and the psychological factors of learning experience (i.e. presence, motivation, cognitive benefits, control and active learning, and reflective thinking). An initial theoretical model of the determinants of learning effectiveness in a desktop VR-based learning environment is contributed. This study makes a significant contribution by bringing us one step closer to understand the potential of desktop VR technology to support and enhance learning. The findings not only enlighten us about what has occurred but also how the learning has occurred in a desktop VR-based learning environment.</p>	J2